Simulation of radar meteor ground illumination to optimize the configuration of the Zephyr meteor radar network

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Abstract

Since meteors occur randomly within the sky, it is crucial to deploy meteor radar networks that maximize the ability to observe meteors and derive upper-atmospheric winds. To accomplish this task, we developed a meteor simulation model in Python to calculate received power as a function of location given transmitter and meteor properties. An interactive and real-time updating meteor simulation map was created to fully understand each simulated meteor. This map displays received power for specified longitude and latitude ranges. Adjusting the meteor, transmitter, and receiver variables allows the user to identify trends and find optimal transmitter and receiver locations. Since there are an unlimited number of unique meteors, simulations were run to create thousands of distinct meteors for each receiver location within specified longitude and latitude ranges. A special focus was placed on finding an ideal location in Colorado for the Zephyr Meteor Radar Network's transmitters and receivers. Ultimately, the improved placement of transmitters and receivers will result in increased sky coverage of potential meteors and their specular trails, which act as natural tracers of upper-atmospheric winds.

Introduction

Meteor: A small body that enters Earth's atmosphere from space, producing a streak of light.

Ablation: Time period where the meteor loses its mass and creates a specular trail in the sky. This phase of the meteor is crucial for an accurate meteor detection.

Meteor radar network: It is used to detect meteors and their winds, and it is composed of both a single transmitter and receiver. The transmitter sends out radio waves which encounter a meteor trail. The processes of the radar backscatter system, head-echo, and the forward scatter method are implemented.

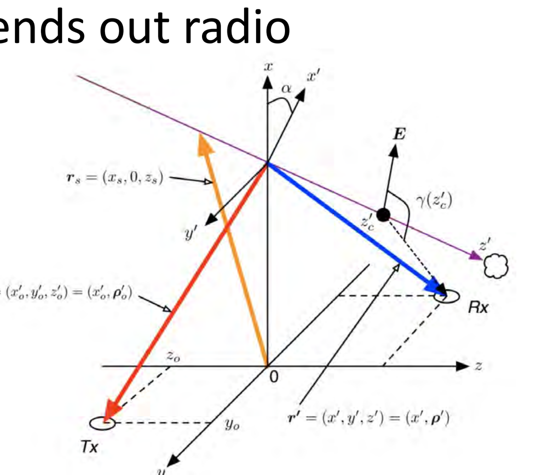

Figure 1: Meteor Radar Network Setup

Zephyr Meteor Radar Network: Planned to be located in Colorado and will view specular meteor trails, which act as natural tracers of upper-atmospheric winds through measurement of the line-of-sight Doppler shift of the reflected radio signal.

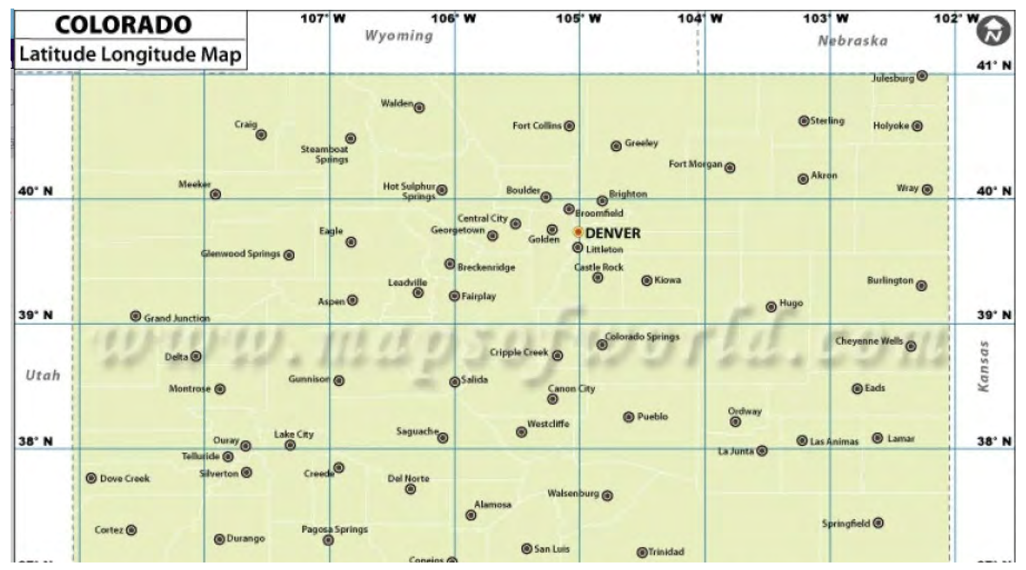

Figure 2: Map of Colorado

Methodology

Meteor Simulation Model

Transmitter location, receiver location, and a meteor are used for the model's setup.

- Receiver and transmitter locations are provided in longitude and latitude coordinates and converted into the yz-plane as seen in Figure 4. The transformation consists of an orthogonal projection onto the Earth and a rotation based on the current simulated meteor.
- To simulate each meteor, the height (m), angle of inclination (°), characteristic length of trail (m), characteristic transverse radius of trail (m), maximum electron line density (electrons/m), location (longitude, latitude), and azimuth angle (°) are used.

$$I(\hat{r}) = \left(\frac{80.6\Pi^2}{c^2}\right)^2 \frac{\lambda^3 |F_N|^2}{p^l p_o^l \sqrt{(p^l+p_o^l)^2+(z^l-z_o^l)^2}} \quad (3.1) \qquad P_r = P_t G_t G_r I(r) \quad (3.2)$$

Figure 3: For each meteor, its analytical power at receiver is calculated (in dBm) with the above equations.

Confirmation of Meteor Simulation Model

- First, it was necessary to verify that the analytical power equation was working accurately when strictly in the yz-plane. To accomplish this, plots with the same parameters as in Vaudrin 2016 were reproduced. Then, the plots from Vaudrin 2016 were compared with the plots our model produced. Upon comparison, each of the meteor and transmitter setups across the specified receiver locations (in the yz-plane) were found to have the same trends in power.
- Next, to allow for real life applications of the meteor simulation, the locations of the transmitter, meteor, and grid of receivers need to be accepted by the model in (longitude, latitude) form. Following that, the latitude and longitude coordinates need to be accurately transformed into the yz-plane since the analytical calculation accepts x,y,z values.

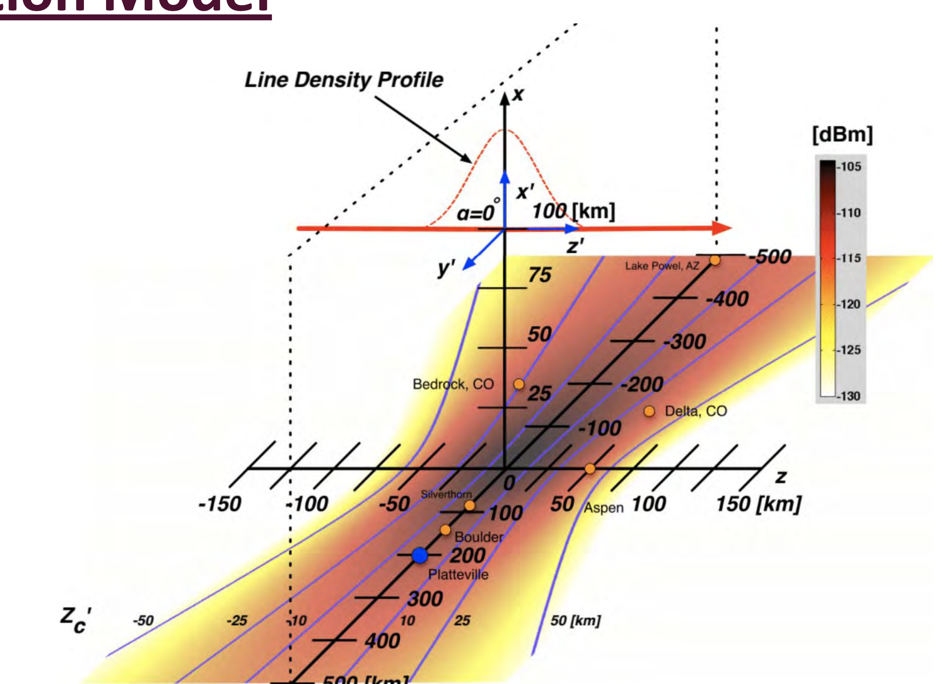

Figure 4: This power at receiver map is from Vaudrin's paper, and it models receiver locations in the yz-plane. This map establishes a basis for plotting the cities in Colorado.

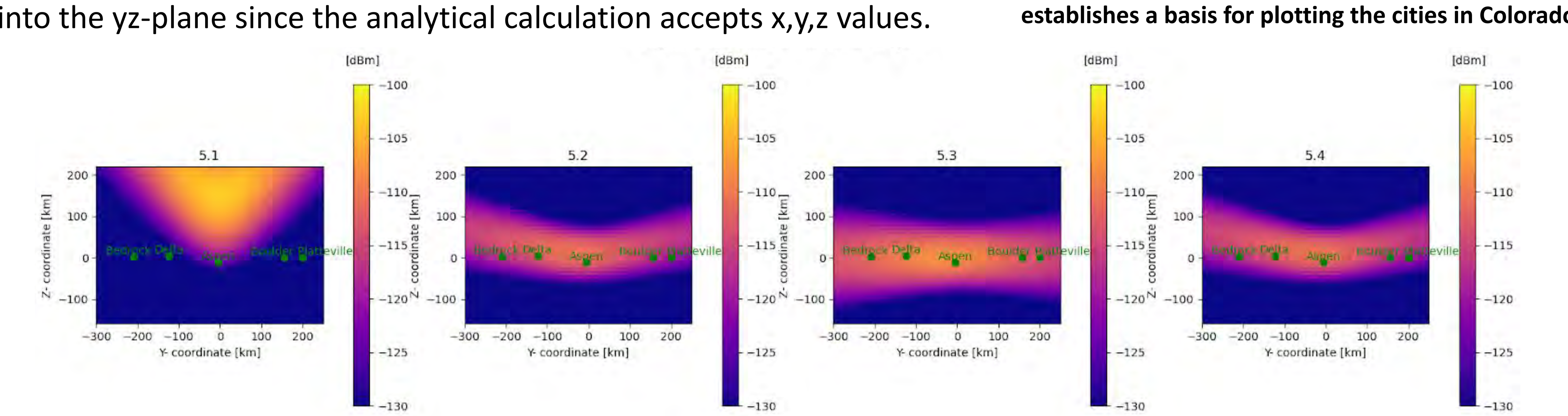

Figure 5: Replicated Power at Receiver Maps

5.1: Transmitter= -200z km, **5.2:** Transmitter= (300y, -200z) km, **5.3:** Transmitter= 200y km, **5.4:** Transmitter= (300y, -100z) km

Development of the Interactive Meteor Plot

Transformation Technique

(Longitude, Latitude) ⟶ (y-value, z-value)

An orthogonal projection onto the Earth using source reference frame WGS84 converts the longitude and latitude values to y and z values and applies the longitude and latitude of the viewed meteor as its origin point. Afterwards, the yz-coordinates undergo a rotation to account for the azimuth angle and the location of the meteor being viewed in the sky.

Simulating Meteor Distributions

The interactive meteor plot is provided with a list of parameters from a user: a range of longitude and latitude values for where in the sky the simulation can randomly place the meteor and the location of the transmitter for the setup. Each random meteor is generated based on the meteor's different properties. The meteor's height, angle of inclination, and l- parallel value can be modeled using uniform distributions of $80\text{x}10^3$ m to $105\text{x}10^3$ m, 0 degrees to 90 degrees, and $5\text{x}10^3$ m to $35\text{x}10^3$ m respectively. While the l- perpendicular value for each meteor is modeled with an exponential distribution from 0 m to 1.5 m and the maximum electron value for the meteor is $10\text{x}10^{13}$.

Results

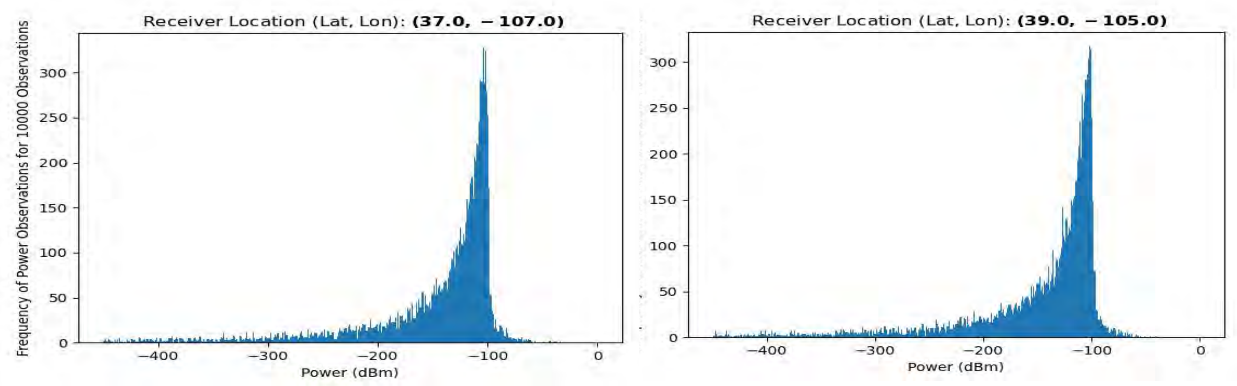

Figure 6: Power Distribution of 10,0000 Simulated Meteors Across Various Receiver Locations

Interactive Meteor Plot

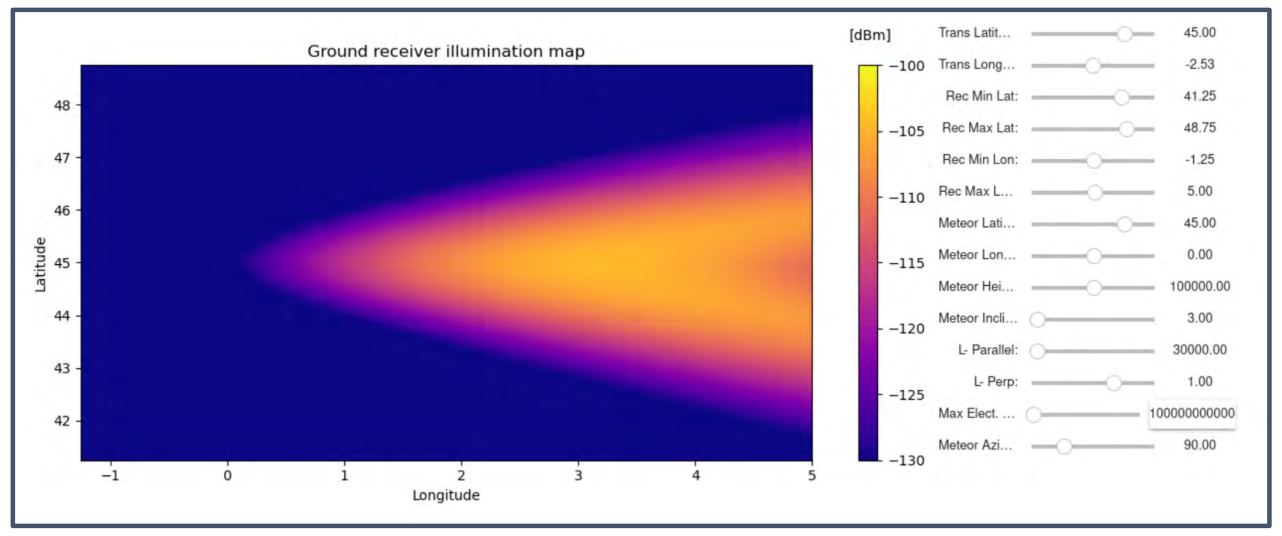

Figure 7: Using this tool, a user can specify a meteor's different parameters, transmitter location, and receiver field of view in real time to see each of their effects on the power.

Conclusion

Overview

- This meteor simulation can be used to simulate power at a specified receiver for any potential meteor in the world and its transmitter and receiver.
- Thousands of random meteors are simulated for a specific receiver location, allowing us to see the level of power at certain receiver locations.
- When the thousands of meteors are developed for each receiver location, plots were generated that determine the percentage of meteors above a certain power threshold.
- An interactive meteor simulation tool was developed to visualize different types of meteors within the sky and see the effects of each of the meteor's properties.
- This tool will be used to pick a transmitter location, so an optimal receiver location in Colorado that detects high power across multiple types of unique meteors is found.

Future Work

- Different types of meteors can be simulated, so a more accurate histogram of power distributions can be created.
- Finding the best location for Zephyr's receivers and transmitters
- Applying this technique to other meteor radar systems

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